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Application of SD model in Analyzing the Cultivated Land Carrying Capacity: A Case Study in Bijie Prefecture, Guizhou Province, China

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Abstract

This paper aims at analyzing the cultivated land carrying capacity (CLCC) with the method of System Dynamics(SD).Taking Bijie Prefecture, Guizhou Province as the research object, the CLCC SD model of Bijie Prefecture has been developed. On the basis of analysis on the main characteristics of BijieCLCC and synthetical adjustment, three available schemes are chosen from various experimental schemes. They are population control-oriented Scheme (Scheme 1), fast economic development-oriented Scheme (Scheme 2), and coordinated development-oriented Scheme (Scheme 3) respectively. Comprehensive evaluation indicates that Scheme 3 is the optimal one, which takes social economic development, population control and cultivated land use into account, and can promote the coordination development of cultivated land, social and economy. This study offers the support of technology and the principle of decision-making for the cultivated land use both in Biejie and other similar regions.

Keywords: Bijie Prefecture Cultivated land carrying capacity System dynamics Simulation.

Ⅰ. Introduction

As China is the most populous country in the world, its natural resources and environmental security has been a primary concern of researchers and politicians for decades [1].China's rapid economic development since the nation's opening up to the outside world has stimulated industrialization, urbanization, and infrastructure development [2], but this progress has also been accompanied by environmental destruction and shortage of natural resources. There is an increasing scarcity of cultivated land [3]. For instance, in China, from 1952 to 2008, the per capita cultivated area had decreased from 0.19 ha to 0.0917 ha. The situation is much severer in karst regions of southwest (SW)China, where fragile

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ecological environment and limited water and land resources, because of the karst features, have been heavily stressed by population growth, economic growth, and enforcement of a environmental protection policy of converting cultivated land back into forest and pasture. For example, in Bijie Prefecture of Guizhou Province, from 1988 to 2008, the cultivated area decreased from 0.0708ha to 0.0474ha which decreased 33.1%, resulting from huge population growth, cultivated area conversion to forest and pasture, and high-speed development of society and economy accompanied by the waste of resources. The problems of cultivated land have become gradually serious in karst regions of SW china, and therefore it is urgent to study cultivated land carrying capacity about it. The analysis of cultivated land carrying capacity (CLCC) is very important to the coordinated development of the population, social economy and ecological environment. Referring to other researchers' definition on carrying capacity[4,5,6], we can define CLCC as the capacity of a country or area's cultivated land, in the foreseeable period, using the conditions of local intelligence, technique etc, can permanently support the population size and human activities level without considerable degradation or damage.

System Dynamics (SD) provides a feedback-oriented modelling framework for learning and communicating about the inherent complexity of CLCC.SD is extremely useful for modelling and analysing complex socio-economic-ecological system. It has been widely applied in many researches including CLCC [7].In this study, taking Bijie Prefecture, Guizhou Province, China, as the case study area, CLCC system dynamics (SD) model is developed for analysis in Bijie, which quantitatively analyzes the dynamic changing of CLCC from 2008 to 2020.

Study area

We select Bijie prefecture of Guizhou province,which includes 8 county-level districts, located in the slope zone of eastern Yunnan-Guizhou Plateau and Southwest China(refer to Fig.1), as the case study area. Bijie, which total land areas is 26853 km^2 and the exposed karst area account for 79.3%, is a typical karst regions. The total population was 770.02×10^4 people and GDP 334.95×10^8 RMB in 2008(calculated at the constant prices of 2005, hereinafter the same).The area has a cool-moist monsoon climate of north subtropical characterized by rainfall abundant. The average water resources here is 134.43×10^8 m^3 a year, but per capita water resources is only 1809m^3, very closed to the internationally recognized severe water shortages cordon(per capita 1700m^3).In 2008,the cultivated area was 364.69×10^3 ha , but per capita cultivated area was only 0.0474 ha far lower than that of china(0.0917 ha) .Because of Physical and chemical characteristics of karst, water and soil erosion is very serious as well as the ecological environment fragile. Water Shortage, especially the engineering water shortage, and low and unstable grain production arising from barren cultivated land make the poverty problem of Bijie be marked by lack of water and deficient in food. Bijie experimental zone, which has three aims: *poverty alleviation and development, ecological construction, and population control*, established by China's State Council in 1988, has made noticeable achievements in social and economic development, but there, according to the "Bijie Statistical Yearbook (2008)" statistics, were still 205×10^4 people troubled by drinking water problems and 59×10^4 rural population in poverty. There are five State-level poverty-stricken counties accounting for 62.5% of the number of county-level districts in Bijie.

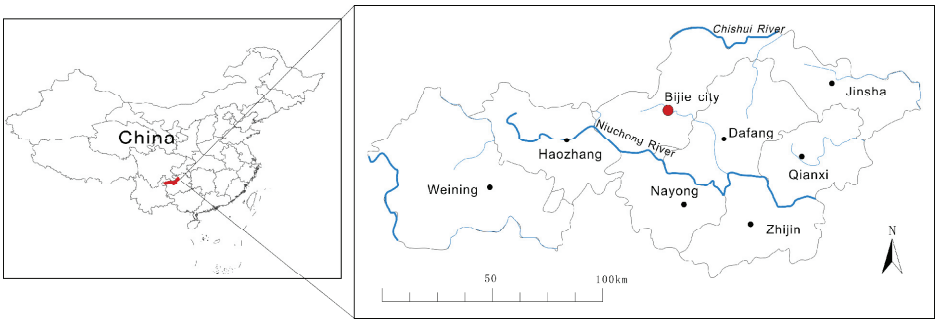


Fig.1 The location of Bijie Prefecture in Guizhou Province, China

Main Characteristics of BijieCLCC Analysis

The Bijie cultivated land carrying capacity system (BijieCLCC) is a complicated system which has three subsystems whose names and characteristics are described as follows.

Cultivated Land Subsystem. From 2000 to 2008, the cultivated area in Bijie had decreased from 394.49×10^3 ha to 364.69×10^3 ha as a result of cultivated area conversion to forest and pasture(decrease in 65.2749×10^3 ha),and development of economy(decrease in 14.50×10^3 ha).During this period， 49.9649×10^3 ha was increased by land consolidation(6.245×10^3 ha.year^{-1}). In

2008,per capita cultivated area was only 0.0474 ha far lower than that of china(0.0917 ha).Extensive cultivation but low output—the multiple crop index is 226.98%,yet the average per unit area yield is only 4301.46kg.ha^{-1}— is the most serious problem in grain production. Per capita grain possession of grain is only 341.05kg people^{-1}.Cultivated land located at the slope above 25°—153.33×10^3 ha—has yet to be harnessed, therefore, it is necessary to consolidate the achievement and go on to carry the policy of converting cultivated land to forestry and pasture in the future.

Economy Subsystem. Since established in 1988, Bijie experimental zone has made noticeable achievements in economic development. From 2000 to 2008, the GDP of Bije had increased from 46.02×10^8 RMB to 334.95×10^8 RMB, which increased 6.28 times. Nevertheless, the per capita GDP of 2008 was only 4350 RMB far lower than that of China (17412 RMB).The proportion of three industries was 26%, 42% and 32% respectively. Overall, the economy development level of Bijie is low but has huge potentials for growth.

Social Subsystem. Bijie is confronted with a lot of problems. The first is the excessive population growth. During 1988-2000, the annual average natural growth of its population is 1.6%.The second is the large quantity of rural population in poverty—59×10^4 people in 2008.The third is the low investment, low level of science and technology, and small quantity of scientific researchers. The average rate of scientific investment as a percentage of GDP is only 0.1%, far lower than that of the corresponding period of China (above 1%).The fourth is the backward in urbanization rate—only 23.5% in 2008.

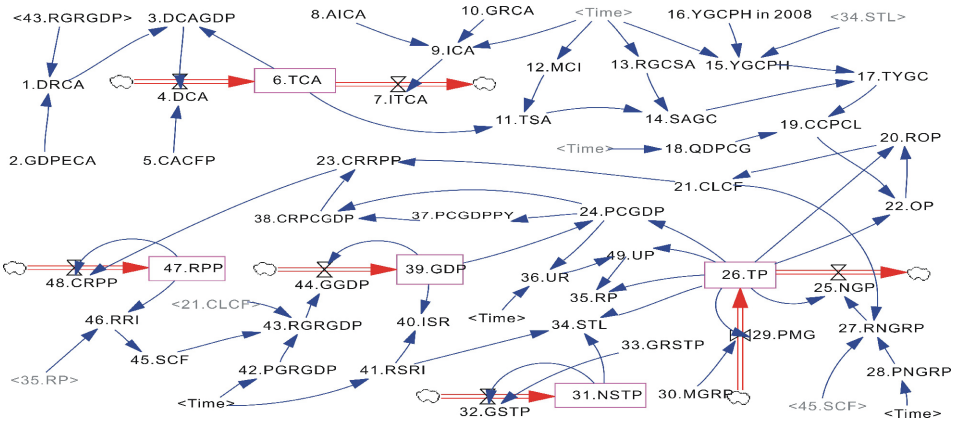
System Dynamics Methodology in Bije CLCC

Model Formulation. Based on the section 3, to capture the interactions between cultivated land, economy and social development, we define the main feedbacks between variables. As the key elements defined, these have to be quantified as variables and their influences have to be formulated mathematically. The BijieCLCCSD model in this study, on the base of the data of 1988 to 2008 in Bijie,

has been developed within Vensim PLE(version 5.10e), and the boundary of the model is the total administrative area of Bijie prefecture. The simulation period ranges from 2008 to 2020. The model includes 50 variables, 49 equations and three major subsystems. The flow diagram for Bijie CLCC is shown in Fig. 2.

Fig.2 The flow diagram for Bijie CLCCSD model

1. decrease rate of cultivated area; 2.GDP elasticity of cultivated area(the ratio of the percentage of change in cultivated area to the percentage of change in GDP); 3.decreased cultivated area by GDP growth; 4.decrease of cultivated area; 5. cultivated area conversion to forest and pasture; 6. total



cultivated area; 7.increase of total cultivated area; 8.average increased cultivated area by land consolidation in recent years; 9.increased cultivated area by land consolidation; 10.growth rate of cultivated area by land consolidation; 11.total sown area; 12.multiple cropping index; 13.ratio of grain crops sown area as a percentage of total sown area; 14. sown area of grain crops; 15.yield of grain crops per hectare; 16. yield of grain crops per hectare in 2008; 17.total yield of grain crops; 18.quantity demanded of Per capita grain; 19.carrying capacity people of cultivated land; 20.ratio of overloaded population; 21.cultivated land constraint factor; 22.overloaded population; 23.change rate of rural population in poverty; 24.per capita GDP; 25.natural Growth of population; 26.total population; 27.real natural growth rate of population; 28.planning natural growth rate of population; 29.population of mechanical growth; 30.mechanical growth rate of population; 31.number of scientific and technical personnel; 32.growth of scientific and technical personnel; 33.growth rate of scientific and technical personnel; 34.scientific and technological level; 35.Rural population; 36.urbanization rate; 37.per capita GDP of previous year;38.change rate of per capita GDP; 39.gross domestic product;40.investment in scientific research; 41.ratio of scientific research investment as a percentage of GDP; 42.planning growth rate of GDP; 43.real growth rate of GDP;44.growth of GDP; 45.social constraint factor;46.ratio of rural impoverishment;47.rural population in poverty; 48. change of rural population in poverty; 49.urban population

*Model Testing.*The developed Bijie CLCC SD model was verified with the data of 2000–2008, and we choose three variables (GDP, TP, CA) for examination. Table 1 shows the difference between the simulation value and the actual value, and the variables have low relative errors, which show that the model is reasonable for the actual situation.

Table 1 Compared results of simulated values and actual values of the main variables

Variables	2003			2006			2008		Relative error
	Actual value	Simulated value	Relative error	Actual value	Simulated value	Relative error	Actual value	Simulated value	
GDP($\times10^8$ RMB)	170.51	176.46	3.49%	264.29	257.95	-2.40%	334.95	334.56	-0.12%
TP($\times10^4$people)	702.02	702.29	0.04%	733.89	732.17	-0.23%	770.02	751.21	-2.44%
TCA($\times10^3$ha)	363.45	372.81	2.58%	364.53	369.16	1.27%	364.69	365.63	0.26%

5. Simulation results

*Schemes Design.U*nder the different planning objectives, many simulative schemes can be attained through adjusting parameters. In this study, three typical planning schemes are designed for further analysis (refer to Table 3). They are population control-oriented Scheme (Scheme 1), fast economic development-oriented Scheme (Scheme 2), and coordinated development-oriented Scheme (Scheme 3) respectively. In addition, scientific research investment, regarded as an important act to promote the cultivated land carrying capacity, has been paid highly attention by all three Schemes.

Table 2 Schemes design by changing parameters

Variables	2008 (base year)	Scheme 1			Scheme 2			Scheme 3		
		2012	2015	2020	2012	2015	2020	2012	2015	2020
RSRI(%)	0.1	1.3	1.6	2.1	1.3	1.6	2.1	1.3	1.6	2.1
PNGRP(%)	1	0.8	0.6	0.6	1	1	1	0.8	0.6	0.6
PGRGDP(%)	11	11	11	11	14	14	14	14	14	14
GRICA(%)	0	0	0	0	2	2	2	2	2	2

Results of the Model Simulation. The simulated values of the main variables for each scheme in BijieCLCC SD model are shown in Table 3.

Table 3 Simulation results of major variables

Variables	2008 (base year)	Scheme 1		Scheme 2		Scheme 3	
		2015	2020	2015	2020	2015	2020
TCA($\times10^4$ ha)	364.69	359.66	357.00	359.74	362.03	359.65	361.47
STL（%）	1.21	2.84	3.48	2.83	3.43	2.85	3.48
YGCPH（kg.ha^{-1}）	4301.46	4842.30	5511.96	4839.08	5493.20	4842.71	5513.08
TP($\times10^4$ people)	770.02	824.43	849.10	835.23	879.92	823.06	847.33
CCPCL($\times10^4$ people)	750.40	798.34	848.60	797.98	857.62	798.37	859.40
OP($\times10^4$ people)	19.62	26.09	0.49	37.25	22.30	24.69	-12.07
RPP($\times10^4$ people)	59.00	8.46	1.29	3.65	0.32	3.31	0.20
UR (%)	23.50	31.42	37.43	32.65	39.30	32.79	39.81
GDP($\times10^8$ RMB)	334.95	585.50	945.86	712.85	1294.65	717.69	1346.71
PCGDP(RMB.People^{-1})	4350	7102	11140	8535	14713	8720	15894

The primary goal of Scheme 1 is population control. Therefore, natural growth of total population decreases year to year and the total population in 2020 is relatively smaller than Scheme 2.But in the meanwhile, during 2008-2020, the rate of GDP growth is slow (small GDP), cultivated area are small (owing to lack of investment for land consolidation), and rural population in poverty are large in comparison with that of Scheme 2. Scheme 2 emphasizes fast economic development but neglecting family planning, so the total population is large in comparison with Scheme 1.

According to the above analysis and the predicted value in table 3, on the whole, Scheme 3 is thought to be a reasonable scheme based on both economic development and population control. It can realize the objective of maximal economic benefit (larger GDP), maximal social benefit (smaller rural population in poverty), and minimal total population simultaneously. In 2020, the carrying capacity people of cultivated land is larger than total population based on Scheme 3,that is, the population overloaded in term of cultivated land carrying capacity is positive. Accordingly, Scheme 3, as it were, is the optimal scheme to improve the cultivated land carrying capacity (more details are shown in Table 3).

6. Conclusions

(1)The cultivated land carrying capacity is a concept with attributes related to both nature and society. This means that it is a complex large-scale system, involving numerous factors including but not limited to population, resource availability, society, economics and technology. These factors interact and restrict each other and act as both positive and negative feedback [8,9].

(2)The scheme of unilaterally pursuing either population control or fast economic development is undesirable for Bijie CLCC. Scheme 3 balancing economic development with population control is the most effective scheme, by which Bijie will gradually improve the cultivated land carrying capacity as well as realize the coordinative development of the cultivated land, social and economy.

(3) Before setting up the BijieCLCC SD model, we made an assumption that Bijie have the potentials to achieve self-sufficient in grain in the foreseeable future by proper planning scheme. The assumption we made is reasonable for the following reasons: (a) the very high transportation cost of grain shipped from other regions owing to the backward transportation in Bije (mountain area), and (b) china, a large population with relatively little cultivated land, on the whole, is not rich in grain, furthermore, Bije, as a non-urban area, should and can make a effort to supply the grain by itself. The simulated results of Scheme 3 support such an assumption, which shows that Bijie can achieve the goal of self-sufficient in grain by the right planning scheme.

(4) Bijie, centrally located the karst regions of SW China, is seriously short of cultivated land and water resources (largely due to lacking water conservancy works). Water resources and cultivated land are closely interconnected with each other in karst area, and should be taken as a whole into a carrying capacity research subject. This research is merely study the CLCC, further research on the water resources carrying capacity should be intensively made in the later study.

Acknowledgments

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